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Environmental Implications of Conservation Tillage A Systems Approach

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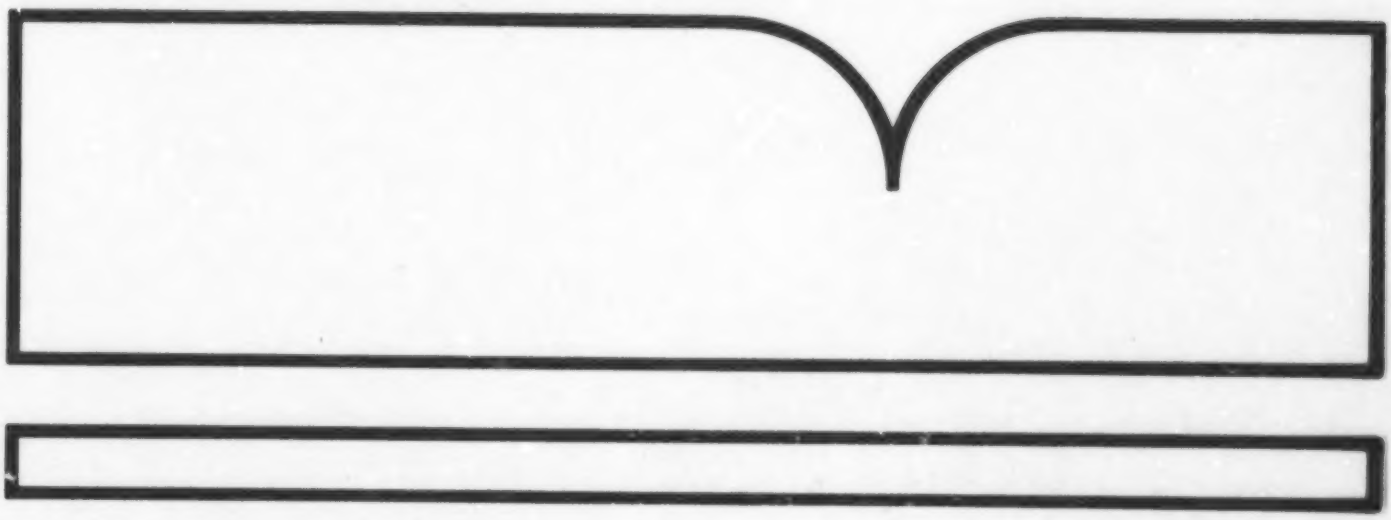

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ENVIRONMENTAL IMPLICATIONS OF CONSERVATION TILLAGE: A SYSTEMS APPROACH

by

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16. ABSTRACT

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Conservation tillage is projected to be the major soil protection method and candidate best management practice for improving surface water quality. Environmental and health implications as well as the agronomic virtues of conservation tillage must be identified and evaluated. A conceptual framework--mass balance approach--is developed identifying those system variables influenced by conservation tillage. A qualitative assessment is then made of the impact, mainly offsite in nature, of conservation tillage on the various exposure pathways of pesticides to human and aquatic ecosystems. Results from such an analysis suggest an increased potential for atmospheric losses of pesticides, a decrease in runoff and soil-erosion-related losses, but an increase in plant-residue-associated erosion as well as increased potential leaching through the unsaturated zone to groundwater. Major concerns, therefore, focus on the quantitative tradeoffs between runoff losses in water, leaching losses to groundwater, and enhanced atmospheric releases. A literature review, in general, substantiated the above speculations as to the impact of conservation tillage on soil properties, processes, and activities, and on pesticide transformation and transport.

Possible environmental implications of conservation tillage that are mainly offsite in nature include: (1) increased direct exposure to farm workers and rural residents due to enhanced volatilization; (2) increased threat of groundwater pollution due to enhanced infiltration and leaching of soluble, persistent pesticides; (3) enhanced instream impact on sensitive ecosystems due to higher pesticide concentrations in runoff and bound on clay-sized particulates; (4) decreased stream bank and stream bed stability; and (5) enhanced algal bloom tendency due to reduced total sediment loads and increased light penetration.

Key Words:

Conservation tillage, mass balance, risk, exposure assessment, environmental implications, offsite impacts, environmental impact, and human health impact.

I. INTRODUCTION

In the last decade, the relationship between agricultural operations and water quality and quantity has become a major national concern. This concern is reflected in efforts to apply effective management practices to control, reduce, or alleviate agriculture's contribution to nonpoint source pollution.

Pollutant discharges from agricultural sources are diffuse in nature and occur primarily during rainfall events. In the resulting runoff or leachate are found pesticides, nutrients, sediments, pathogens, and easily oxidizable organics that may adversely affect water supplies, either from a human or from an environmental perspective.

To reduce the amount of pollutants entering streams, air, or groundwater, a number of control methodologies, known as Best Management Practices (BMPs), were identified in the Federal Water Pollution Control Acts of 1972 and 1977. These BMPs provide a means of controlling the agronomic aspect of the agro-ecosystem that is the source of pollution and to a lesser extent the hydrologic and aerodynamic properties of the soil-plant system that regulates the rate of delivery and quantity of the pollutants reaching surface water, groundwater, and the atmosphere.

A wide array of management practices have been developed to maximize agricultural productivity. These practices can be divided into two classes: (1) those that affect the physical system (e.g. tillage and structural controls) by influencing erosion through changes in soil erodibility and cover, slope steepness, and slope length, and by influencing runoff through alterations in the soil infiltration rate, moisture storage capacity, and hydraulic conductivity, and (2) those that affect the properties of nonconservative pollutants or control their input relative to timing and level of application (e.g., environmental properties, formulations, and application methodologies). Both conventional

and conservation tillage fall into the first class. Conservation tillage is actually an array of practices that decreases the amount of exposed soil surface by retaining crop residues and reducing soil disturbance.

Research by Unger (1977, 1978, 1979), Crosson (1981) and Crosson and Brubaker (1982) projected that conservation tillage will be used on 50 to 60 percent of the tillable cropland in the United States by the end of the century. Estimates by the U.S. Department of Agriculture have run as high as 95 percent. The adoption of this "single management practice", therefore, would affect 210 to 400 million acres of row crops. Agriculturally, this would be a quantum change in management systems comparable to that which occurred in the 1950s, when traditional crop-rotation-based farming was transformed into synthetic-chemical based agriculture.

Such an extensive change in agricultural management gave rise to concerns about the total environmental impact of the candidate BMPs (Bailey and Waddell, 1979; Bailey and Swank, 1983). Conservation tillage could offer large potential reductions in sediment loss to surface waters, but also could result in increased pesticide exposure to the environment through runoff to streams and impoundments, percolation to groundwater and loss to the atmosphere.

One of the indicated purposes of this conference is to define and evaluate the impact of the nearly ubiquitous implementation of conservation tillage on both environmental quality and human health.

The objectives of this paper are to:

- develop a conceptual, mass-balance framework to assess the potential impact of conservation tillage from a pesticide perspective on the environment and human health,
- make a qualitative analysis of the changes in pesticide exposure routes due to use of conservation tillage, and

- elucidate the environmental implications of the widespread implementation and use of conservation tillage.

II. AGRO-ECOSYSTEM DESCRIPTION

Understanding the relationship between agricultural management practices and environmental quality requires an analysis of the complete agro-ecosystem. System analysis permits an enhanced understanding of the many dynamic interactions among agro-ecosystem components from a physico-chemical standpoint. This approach is holistic; that is, an isolated study of the parts will not permit the comprehensive understanding of the complete system because the separate parts are linked interactively. A perturbation, e.g. widespread change in management practices in one part of the system, will not only affect that part but the whole system--terrestrial, aquatic, and atmospheric compartments.

An agro-watershed has definite physical boundaries and its response to pesticides or other chemical pollutants is determined by the combination of physico-chemical characteristics of the soils and chemical themselves, topography, vegetation, geology, and well and drainage networks. Inputs can be categorized as deterministic (e.g., timing of pesticide application) or stochastic (e.g., occurrence of rainfall). The system response, therefore, is stochastic. Outputs include food and fiber plus sediment, pesticides, nutrients, heavy metals, and easily oxidized organics, plus residues on the land surface, in runoff and leachate, and in the air.

The agro-ecosystem is a combination of hydrologic, agronomic, ecological, social and economic subsystems. The watershed level response, as seen from Figure 1, can be multimedia in dimension (land to water, land to atmosphere, and atmosphere to land).

The hydrological cycle plays an important role in the transport of pesticides through a riverine system to its estuary. Possible pesticide transport routes

include surface runoff, interflow to surface water, percolation to groundwater, and direct loss to the atmosphere.

Chemical characteristics of the pesticide that influence pollutant transport from soil include: (1) ionic state (cationic, anionic, basic or acidic), (2) water solubility, (3) vapor pressure, (4) partition coefficient, (5) hydrophobic/hydrophilic character, and (6) chemical and biological reactivity. These properties combined with the initial amount of pesticide applied determine how much pesticide potentially can be transported along each route. Sorption primarily determines whether the primary transport route is through overland flow, subsurface water movement, release to the atmosphere, or sediment-bound movement (both water and aeolian modes of transport).

III. FRAMEWORK TO ASSESS POTENTIAL IMPACT OF CONSERVATION TILLAGE ON THE ENVIRONMENT AND HUMAN HEALTH

A systematic analysis of the environmental impact of conservation tillage must be based on defined endpoints for impacts and on a step-by-step approach showing how each endpoint is reached. The basic premise of our approach is the need to know the environmental and human health risks derived from widespread adoption of conservation tillage. The risk posed to any species is rather simply defined as the probability of damage, death, illness, functional impairment, ecosystem alterations, etc. Such damage only occurs when the affected specie is exposed to a harmful agent, usually in a probabilistic sense.

The major concern for health and environmental damage from conservation tillage is the associated use of pesticides. In short, how does conservation tillage influence the probability of pesticide exposure to biological species (including man) and what is the overall ecosystem function/response? The routes or pathways of exposure set the boundary conditions for this problem (Table 1). For humans, major potential routes include: inhalation of dusts,

aerosols, and vapors; ingestion of contaminated fish, foodstuffs and soil; ingestion of contaminated drinking water; and dermal absorption from air, water, or soil. For fish the exposure routes include contact with ambient waters and sediments, and bioaccumulation. Similarly, wildfowl exposure routes include ambient contact, bioaccumulation, and direct ingestion. The interrelationships between sources, pesticide BMPs, and exposure concentration to biological, environmental, and human health risks is seen in Figure 2.

Any serious attempt to assess the exposure to pesticides used in conservation tillage should include all application-related sources of pesticides and routes of exposure (Figure 3) and properly treated on-site exposures (e.g., birds in agricultural fields) and off-site exposures (e.g., fish in drainage waters). To simplify the problem, however, we have chosen to concentrate on off-site concerns (e.g., drinking water contamination via leaching) thereby reducing the analysis problem to a careful look at the pesticide fluxes derived from conservation tillage systems. Thus, we can immediately examine questions concerning the impact of conservation tillage on pesticide runoff (dissolved and particulate-bound forms), leaching, and volatilization pathways.

The basis for any quantitative analysis of <u>fluxes</u> must be the mass balance approach. A qualitative description of the conservation tillage system can be written as:

"<u>SOURCE</u>"		"<u>SINKS</u>"
PESTICIDE APPLICATION	=	(DEGRADATION LOSSES + VOLATILIZATION LOSSES + EROSION + RUNOFF + LEACHING + HARVEST REMOVAL + Δ STORAGE)

Our basic problem is to understand how each of the above terms is influenced by conservation tillage. It is convenient to further describe the conservation tillage system as having four interacting components with a mass balance written for each.

Consider such a system as depicted in Figure 3.

For the plant canopy and crop residue we can write:

APPLY1 = DEGRADATION (PHOTO + CHEMICAL) + VOLAT1 + PLANT UPTAKE
+ HARVEST + PLANT METABOLISM + FOLIAR AND RESIDUE WASHOFF
+ EROSP + VOLAT2 - VOLAT3 + Δ STORAGE

Next for the soil surface zone we can write:

APPLY2 = DEGRADATION (PHOTO + CHEMICAL) + VOLAT3
+ EROSS + RUNOFF + LEACHING1 - VOLAT4
- FOLIAR/RESIDUE WASHOFF + Δ STORAGE

For the root zone we have:

APPLY3 = DEGRADATION (CHEMICAL + BIOLOGICAL) + VOLAT4 - VOLAT5
+ LEACHING3 - LEACHING2 + PLANT UPTAKE
+ Δ STORAGE

Finally, for the zone below the root zone we have:

Δ STORAGE = LEACHING3 - LEACHING4 - DEGRADATION (CHEMICAL) - VOLAT5

Note in the above equations that some processes are internal to the system. We are more interested in the environmental fluxes out of the system for our exposure analysis--specifically, VOLAT1, HARVEST, EROSP, VOLAT2, EROSS, RUNOFF, VOLAT3, and LEACHING2 and 4. Recall that VOLAT1, VOLAT2, and VOLAT3 represent vapor losses from the plant canopy, surface residue, and soil surface, respectively. EROSP, EROSS, and RUNOFF represent erosion losses in plant residue and soil and runoff losses in overland flow, respectively. LEACHING2 represents leaching below the root zone and HARVEST represents removal via plant burdens.

Consider a mass-balance equation for the soil profile from the surface to the bottom of the root zone derived in terms of the soluble pesticide form, C_w. It is readily shown that a reasonable approximation of this system is:

$$\frac{\partial C_w}{\partial t} = \frac{(D_a + D_w)\ (\theta_{fc} + K_H\ (1-\theta-\rho_s-\rho_p)}{\varepsilon} \frac{\partial^2 C_w}{\partial z^2} - \frac{V_w\theta+V_a K_H(1-\theta-\rho_s-\rho_p)}{\varepsilon} \frac{\partial C_w}{\partial z}$$

$$- \frac{[\Sigma k_w \theta_{fc} + \Sigma k_s K_D^s \rho_s + \Sigma k_p K_D^p \rho_p + \Sigma k_a K_H (1-\theta_{fc}-\rho_s-\rho_p)]}{\varepsilon} C_w$$

$$\frac{[EROSS\ K_D^s\ \rho_s + EROSP\ K_D^p\ \rho_p + kT + RUNOFF]\ C_w}{\varepsilon}$$

where: C_w = soluble pesticide concentration

D_a, D_w = diffusion-dispersion coefficients for air and water

θ_{fc} = volumetric water content at field capacity
θ = volumetric water content
K_H = Henry's constant

ρ_s, ρ_p = soil and plant residue density

K_D^S, K_D^P = partition coefficients for soil and plant residue

V_W, V_a = velocity vectors for water and air

$\sum k_w$, $\sum k_s$, $\sum k_p$, $\sum k_a$ = sum of first-order rate constants for degradation in water, on soil, on plant residue, and in air

EROSS = soil erosion rate

EROSP = plant residue erosion rate

kT = transpiration rate of contaminated soil water

RUNOFF = water runoff rate

z = vertical depth dimension

and finally,

$$\varepsilon = \theta_{fc} + K_D^p \rho_p + K_D^s \rho_s + K_H\ (1 - \theta_{fc} - \rho_s - \rho_p)$$

The above equation is useful because it provides a means to isolate major system variables influenced by conservation tillage and examine the nature of that impact. Note that the environmentally relevant variables are θ_{fc}, V_w, V_a, ρ_s, ρ_p, EROSS, EROSP, and RUNOFF. These variables are not independent in every case and in some cases their dependence may be highly non-linear. For

example, $V_w = f(\theta_{fc}, RUNOFF, \rho_s)$. The chemical-specific variables include D_a, D_w, K_H, K_D^p, K_D^s, $\sum k_s$, $\sum k_p$, $\sum k_w$, and $\sum k_a$. Here again, these values may be dependent and related in a non-linear fashion. The point is that the above equation enables a ranking of impacts if we know the impact of conservation tillage on the relevant variables.

Trends in chemical properties give a clear indication of the impact of chemical properties on the resulting fluxes. For example as K_D^p and K_D^s increase then EROSS, EROSP, and RUNOFF decrease. If they decrease, then the dispersive and advective terms (the first two in the equation) increase with the attendant increase in leaching. Additional observations can be noted once a clearer picture of the relative impact of conservation tillage on each variable becomes apparent.

It is useful to rank the impact that conservation tillage has on each of the terms in the above mass balance equations. Table 2 identifies the major fluxes of concern and the off-site exposure routes and presents a judgemental ranking of the impact of conservation tillage relative to conventional systems. Some interesting (but not surprising) observations are readily obvious. Atmospheric losses of pesticides are likely to increase because more are applied to plant, soil, and residue surfaces. Runoff and soil-erosion-related losses will decrease but plant-residue-associated "erosion" will increase. Leaching will increase.

The above qualitative ranking has served to narrow the problem somewhat and indeed the major concern appears to be the tradeoff between runoff and the resulting impacts on various receptors in surface water and the leaching losses to groundwater. Another potential concern is the loss of pesticides from crop residue through the volatilization pathway. Research is needed to evaluate this tradeoff in more detail.

IV. ASSESSMENT OF THE IMPACT OF CONSERVATION TILLAGE ON SOIL PROPERTIES, PROCESSES, AND PESTICIDE TRANSPORT AND TRANSFORMATION

In the previous section we developed an approach to identify major system variables influenced by conservation tillage and speculated on the impact on each by conservation tillage. In this section we will attempt to document from the literature our speculations on the impact of conservation tillage on these relevant variables (Table 3).

A. Transformation Processes

Few actual data exist on pesticide transformation rates in soils subjected to conservation vis-a-vis conventional tillage. Some implications of likely behavior can be inferred, however, from the documented changes in soil properties. Specifically, the increase in organic matter levels (Dick, 1983; Blevins et al., 1983; Langdale and Leonard, 1983; Langdale et al., 1984) and the increase in microbial activity of the upper soil layers (Doran, 1980) combined with a higher average moisture content, less rapidly changing and slightly lower temperatures (Gupta, et al., 1982), and the possibility of improved oxygen transport in the upper soil layers due to reduced bulk density and increased bioturbation should increase the overall effective rates of both biological and chemical oxidation. Indeed, both aerobic (initially), facultative, and anaerobic activity may later be increased as a result of the higher moisture levels and initially rapid biological degradation of the organic residue. In addition, the elevated moisture levels should increase mass transfer and diffusion rates of the pesticides to, into, and from soil such that soil-mediated reactions are also accelerated.

The presence of large quantities of organic matter on or in the upper soil profile combined with increased biological activity should produce acidic conditions that, in turn, will possibly require increased lime and ammonia additions for both pH and nutrient adjustments. As a result, it is likely

that pesticides in the upper soil zones will be subjected to wider swings in pH than present under conventional tillage, and therefore, both acid and base hydrolysis reactions should be accelerated. Research results confirm that soil pH does decrease with conservation tillage (Dick, 1983; Blevins et al., 1983). With regard to transformation in the lower soil zones, there is not enough information to draw any definitive conclusions, but it would appear that there should be no significant difference as compared to conventional tillage. A paucity of information exists on pesticide transformation rates in the lower horizons.

The real unknown in this analysis is the net effect of the vastly increased surface area of organic matter left on the soil surface relative to pesticide transformation pathways and rates. Even though most "new" pesticides have low partition coefficients, the large amount of organic matter present combined with its high surface area and the generally higher pesticide usage for conservation tillage would imply a potentially pivotal role for this material in pesticide degradation and transport. Nominally, one would assume that pesticides intercepted or sorbed on this organic surface could undergo photolysis reactions to a much greater degree and for a longer time than soil-applied chemicals in conventional tillage. Actual quantification of this hypothesized role is an urgent research need.

B. Pesticide Transport to Other Environmental Media

In this section, we will briefly examine the effect of conservation tillage on the four major transport pathways--runoff, erosion, leaching, and volatilization--on the intermedia transfer of pesticides to surface water, to groundwater, and to the atmosphere. A summary is given in Table 1.

1. Runoff

Conservation tillage reduces the total amount of runoff reaching streams, i.e., reduces runoff volume (Harold and Edwards, 1974; Langdale et al., 1978;

Langdale et al., 1979; Thomas et al., 1982; Burwell and Kramer, 1983; Langdale et al., 1983). The extent is a function of such factors as the specific type of conservation system, soil properties, slope, amount of crop residue, crop type, percentage of surface coverage and antecedent soil moisture among other factors. For example, Langdale and coworkers (1979) found that, in a comparison of conventional versus no-till, double-cropped barley followed by grain sorghum with fescue, annual runoff was decreased from 22.8cm to 12.0 cm. More potentially important from an environmental standpoint was that runoff was reduced 90% from May through July, during which time both sediment, sediment-bound and dissolved pesticide transport potential is usually the highest. Conservation tillage protects the surface of the soil at a time when the soil is the most susceptible to erosion and pesticide runoff.

Pesticides of varying physical, chemical and toxicological characteristics have been found in runoff; the data has been summarized by Leonard and coworkers (1976), Wauchope (1978) and by Baker and Johnson (1983). Factors that influence runoff (and erosion) and thus pesticide transport in overland flow include land management and conservation practices, rainfall characteristics, land usage, and soil erodibility.

Little field research has been reported comparing pesticide losses in runoff between conservation and conventional tillage. Consequently, few data exist to parameterize either water balance or pesticide transformation properties under conservation tillage for modeling purposes. Baker and Johnson (1979) found that fonofos was lost in greater amounts from till-plant systems than from either conventional or ridge plant systems; the greater part of losses being in runoff.

In general for those pesticides with low or moderate K_p or K_{oc}, the major mode of transport is in runoff rather than delivery in sediment. The converse is true for pesticides with high K_p or K_{oc}. The concentration is higher on the

sediment, but the greater load is carried by runoff because of the greater quantity of water than soil transported by overland flow. For example, in a study on these same watersheds (Smith et al., 1978), it was found that six herbicides (atrazine, cyanazine, diphenamid, trifluralin, propazine, and 2,4-D) showed higher concentrations on sediment than in runoff, but the total mass of pesticide transported in the water phase was much greater than in the sediment phase because of the greater mass of water compared to the mass of sediment.

Caution must be exercised when reviewing the literature because broad, sweeping generalizations have been made that the major transport route is pesticide bound on sediment rather than dissolved in runoff. These conclusions were based on early results for the persistant, chlorinated hydrocarbons with high Kp's. Insecticides and herbicides today generally have much lower K_p and K_{oc} (< 1000 compared to the chlorinated hydrocarbons, K_{oc} > 10,000). They also are much less persistant in soils.

Because, in general, the application rates of pesticides for conservation tillage are higher than for conventional tillage systems, the potential concentration to be lost via overland flow is greater. This fact, all things equal, would be significantly more important for those rainfall-runoff producing events occurring on or shortly after the day of application.

More sources for contribution to runoff as defined in Figure 3 are available under conservation compared to conventional tillage. Foliar washoff and crop residue washoff, as well as "extraction" from the soil surface, contribute to runoff and overland flow to surface water. The contribution of each source to the total pesticide load being delivered in runoff via overland flow is not known and no field studies to quantify these loads are underway. The affinity or retention characteristics of foliar and crop residue surfaces remains to be

determined. How different it is from the partitioning extimates based on organic carbon content of soils also remains to be determined.

Conservation tillage decreases runoff and increases infiltration by both decreasing the formation of surface crusting and by increasing and maintaining macropores in the surface horizon. This is due to increased organic matter content and bioturbation in the plant root zone.

2. Erosion

Erosion may be caused by both water and wind and the erosional processes may generate both soil particles and organic detritus. Both of these substrates may be vehicles to transport pesticides (and nutrients as well) offsite to receiving surface water or some other receptor. Wind blown dusts have been found to be carriers for chlorinated hydrocarbon insecticides (Cohen and Pinkerton, 1966) and such fugitive dusts have been transported hundreds or thousands of miles from their sources.

Conservation tillage reduces water erosion and soil losses compared to conventional tillage (Mannering and Burwell, 1968; Harold and Edwards, 1974; Langdale et al., 1978; Fenster and McCalla, 1970; Fenster, 1977; Reicosky, et al., 1977). For example, Langdale and coworkers (1978) found a reduction in soil erosion in the Southern Piedmont from 26.26 metric tons/ha (11.71 tons/acre) with conventional tillage to 0.131 metric tons/ha (0.06 ton/acre) with no-tillage. No chemical data were given so direct comparison could not be made on the impact of tillage systems on the flux of pesticides loss from the small upland watersheds.

Although soil loss is reduced many fold by the use of conservation tillage, caution must be exercised in ruling out completely the route of water erosion as an important transport route. Erosion is a selective process whereby the finer particles--clay and organic matter (organic matter moved as a particulate

or bound onto inorganic substrates)--are delivered to streams. Because sorption capacity is highest with the smaller particle size and because organic matter has been found to be best correlated with sorption for most classes of pesticides, these two fractions may be "hotter" than the whole soil.

Water erosion may detach and transport crop residue detritus from the field and deliver it to surface water. Pesticides bound on crop residue may, therefore, enter surface water in this manner. The importance of this transport route, the ease of desorption from the crop residue, and the flux/loads generated from this source are not known presently.

3. Leaching and Groundwater

Conservation tillage, as stated earlier, reduces the volume of runoff by an average of 25% (Baker and Johnson, 1983); the exact degree of reduction is highly variable and site-specific. Conservation tillage favorably influences those physical soil properties that increase infiltration and overall water storage. Under conservation tillage organic matter content, soil aggregation and soil structure are increased; the continuity of macrochannels in soil is maintained, thus permitting better communication to subsoil; bioturbation near the surface is increased; and overall bioactivity is increased compared to conventional tillage systems (Edwards, 1982; Unger and McCalla, 1980; Klute, 1982; Larson and Osborne, 1982; and Smith and Rice, 1983). The property bulk density is increased or decreased depending upon soil type and climate conditions. The environmental properties that most influence the potential of a pesticide to leach to subsurface waters (interflow) or to groundwater are its persistence and mobility through soil and subsurface porous media. Persistence is a collective term representing a chemical's overall behavior with respect to degradation processes and volatilization. Mobility is related to the pesticide distribution coefficient and water solubility of the pesticide.

Certain pesticides have been found in tile drainage water. Gold and Loudon (1982) reported atrazine at a concentration range of 20 to 170 ppb in tile drainage water generated by a storm 4 days after planting. Of the 1.4 kg/ha applied at planting, 1.0% and 2.2% were lost in tile flow from conventional and conservation tillage, respectively. Overland flow concentrations were 2 to 4 times higher than those found in tile flow.

Pesticides have been found in groundwater (Harkin et al., 1982; Hebb and Wheeler, 1978; Peoples et al., 1980; Rothschild et al., 1982; Spalding et al., 1979; Wehtze et al., 1983; and Zake et al., 1982; Cohen et al., 1984). Cohen and coworkers (1984) reported that a total of 12 pesticides had been found in the groundwater of 18 different states. These include alachlor, aldicarb (sulfoxide and sulfone), atrazine, simazine, bromacil, carbofuran, dacthal, DBCP, 1,2, dichloropropane, dinoseb, EPB, and oxamyl. The majority of these fall into three categories--triazines, carbamates, and low molecular weight hydrocarbons. In many cases, these herbicides/nematicides were found in groundwater below sandy soils under intense irrigation. Groundwater concentration levels were in the medium parts-per-trillion to the low parts-per-billion range.

4. Volatilization

Pesticides applied to crops may reside in or on one or more surfaces (Figure 3)--crop canopy, crop residue, and soil surface. The pesticides may ultimately be incorporated into the soil following the initial rainfall or by mechanical incorporation. Tillage practices may influence the distribution between the crop residue surface and the soil surface. In the case of conservation tillage, the surface crop residue acts as a physical barrier preventing pesticides from reaching the soil surface, particularly broadcast sprayed herbicides. Several review articles summarize research on chemical, environmental, and soil factors influencing vapor transport and loss of pesticides from both

soil incorporated and surface applied pesticides (Spencer, 1970; Spencer, et al., 1973; Spencer and Claith, 1977; Spencer et al., 1982; Guenzi and Beard, 1974; Farmer et al., 1984). Little is known from a predicitve sense about the magnitude of vapor losses from foliage-applied pesticides. Worker reentry times for foliar-applied insecticides is a public health concern.

The major difference between conservation tillage and conventional tillage from a pesticide transport and export standpoint is that pesticides are applied mainly to the crop residue surface in the former case and directly on or incorporated into the soil in the latter case. This is a major difference because herbicides, in particular, are normally applied as a spray and not as a granule.

Concern has been expressed (Martin et al., 1978; Baker, 1980; Baker and Laflen, 1983; Baker, 1985) about herbicide volatilization from surface crop residue, but the magnitude of the problem has not been quantified. We do not know whether the herbicide is adsorbed or absorbed by the crop residue. We also do not know whether the chemical can be desorbed from crop residue surfaces or diffused to the crop residue surface from its interior and lost to the atmosphere. One would expect higher volatility losses from chemicals that have a high vapor pressure and a low partition coefficient. Picloram was not found to be adsorbed by wheat straw (Grover, 1971).

With surface temperatures rising to 50 to 60°C at times, volatilization from crop residue may be a major transport pathway from the crop/soil system to the atmosphere. Both on- and off-site human impacts will be determined by the initial concentration of the pesticide, flux from the crop residue, photostability, drift characteristics, and inhalation toxicity of the pesticide.

If pesticide volatilization from the crop residue is a major environmental transport pathway, then improvements in application technology may be needed, e.g. use of granular formulation and/or application technology whereby the

residue is disturbed and the pesticide (whether spray or granular form) is applied mainly to the soil surface. The presence of crop residue then would decrease pesticide loss by increasing the diffusion path length to the atmosphere, by lowering the soil surface temperature, and by decreasing the wind velocity at the soil surface.

V. ENVIRONMENTAL IMPLICATIONS

It is not clear either from model simulations or actual data what the net environmental impact will be from pesticides that are applied in conjunction with the widespread adoption of conservation tillage. Although it is clear that both surface runoff water and sediment volumes will be reduced and that many degradation processes might be accelerated, it is possible that the increased amounts and frequency of pesticide use will offset this apparent benefit.

Clearly, the potential for direct exposure to farm workers and rural residents will be increased due to higher pesticide rate of nongranular formulations, enhanced volatilization losses and offsite drift from aerial applications. Similarly, the decreased surface runoff will result in a general increase in potential threats to groundwater from mobile, soluble and persistent pesticides. Fines enrichment and the increase in organic particulate runoff could result in sufficient sorbed pesticide at higher concentrations such that the total sediment-bound loads could exceed those of conventional tillage on the same fields. Similarly, even though the runoff water volumes are reduced, higher concentrations of pesticides in it could produce more acute impacts in receiving waters and even greater total loads than that resulting from conventional operations.

One potentially serious environmental impact that needs to be evaluated, although not related to pesticides, is a direct result of the projected major decrease in sediment loadings to surface streams. Under such drastic changes in load, data (Simons and Li, 1980) suggest that stream bed and bank erosion

rates may be greatly increased, thereby seriously threatening the habitats of upland stream and riverine aquatic organisms. Moreover, a major reduction in average instream sediment concentrations without a concurrent major reduction in nutrient and carbon loads to surface waters could aggravate the tendency toward stream/river algae blooms produced by an increase in light penetration ability.

Obviously, targeted field studies are needed to quantify these various environmental concentrations and fluxes, to verify the projected changes, and to parameterize assessment models for subsequent regional and national analyses of water quality and human exposure impacts likely to result from the widespread adoption of conservation tillage.

Conservation tillage increases infiltration and hydraulic conductivity, which would favor the leaching of pesticides. Increased organic levels in surface soils would promote the retention of those pesticides having a moderate K_p, K_{oc}. The root zone environment would experience higher biological activity and a different distribution of microorganisms would be found (Doran, 1980). Aerobic microorganism counts increased 10 to 80% in the 0 to 7.5cm depth and anaerobic bacteria increased 60 to 300% in the reduced tillage plots compared to conventional tillage. In the 7.5 to 15cm depth, populations of facultative anaerobes and denitrifiers were higher with no-till. This indicates that conservation tillage soils are less oxidative than conventional tillage soils.

The significance of these different types of microbial populations as a function of tillage systems on the relative resistance of a pesticide to degradative processes is unclear at this time. The nature of degradative environments in terms of both biological and chemical processes as a function of the depth in the profile and in the porous media above the groundwater aquifer needs to be defined. Appropriate kinetic expressions must be developed to quantitatively describe degradation processes all the way to the aquifer.

VI. SUMMARY AND CONCLUSIONS

Conservation tillage looms on the horizon as the major soil protection method and candidate best management practice for improving surface water quality. Conversion from conventional to conservation tillage practices is proceeding at an accelerating rate. Specifically, it is estimated that by the turn of the century about 95% or 400 million of the 420 million acres devoted to row crops in the United States will be cultivated by conservation tillage. This quantum level change in management systems is comparable to that which occurred in the 1950s, when rotation-based agriculture was changed to synthetic-chemical-based agriculture.

Benefits of conservation tillage as brought out by papers at this conference include: reduced erosion, lower sediment-associated pesticide losses to surface water, increased infiltration of water into the soil, reduced runoff, higher moisture content in the surface horizon, reduced energy use and costs, and improved long-term soil and crop productivity.

Conservation tillage also raises environmental concerns becasue of increased pesticide application rates, lack of soil incorporation of pesticide, and potentially enhanced pesticide volatilization fluxes to the atmosphere.

Potential environmental implications of conservation tillage characteristics that are mainly off-site in nature include: (1) increased direct exposure to farm workers and rural residents due to enhanced volatilization, i.e. greater acute or chronic impact; (2) increased threat of groundwater pollution (greater infiltration and leaching of soluble and persistent pesticides), i.e. enhanced adverse impacts on aquifers for drinking water and irrigation water supplies; (3) greater total sediment-bound pesticide loads (due to clay particle size enrichment) and greater instream impact on sensitive ecological systems; (4) greater pesticide concentrations in runoff (nonsoil incorporation of pesticides)

and greater instream impact on sensitive ecological systems; (5) decreased stream bed and bank stability (decreased total erosion and soil loss and increased stream scour carrying capacity) with riparian habitats threatened; and (6) reduced stream and lake sediment concentrations resulting in increased light penetration and enhanced algal bloom.

One approach to fully sustain the extensive implementation and use of conservation tillage and obviate the potential adverse environmental implications would be the periodic use of primary or conventional tillage practices and adequate crop rotation. For example, in the Southeast the use of primary tillage once every 3 to 5 years and rotation of the cash crop, i.e. soybeans and corn, appears to be one feasible alternative.[1] Primary tillage would be done in the fall preceding the sowing of the double crop, wheat; the crop would provide cover to reduce erosion and runoff during the period of intense rainfall that occurs before conservation tillage practices are begun.

Answers to questions about the environmental impact and implications of nationwide acceptance and implementation of conservation tillage as a best management practice will require incisive, innovative field and laboratory research to quantify water balance components and transformation rates and to parameterize assessment models subsequent to regional, national, and site-specific assessments.

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[1] Personal communication, George W. Langdale.

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TABLE 1 ENVIRONMENTAL PATHWAYS FOR CHEMICAL CONTAMINANTS

PESTICIDE SOURCE	TRANSPORT PROCESS	EXPOSURE PATHWAY	RECEPTER (POPULATION AT RISK)
CANOPY	VOLATILIZATION	INHALATION/SKIN CONTACT	HUMAN ANIMALS
CROP RESIDUE	VOLATILIZATION	INHALATION/SKIN CONTACT	HUMAN ANIMALS
SOIL SURFACE	VOLATILIZATION	INHALATION/SKIN CONTACT	HUMAN ANIMALS
ROOT ZONE AND BELOW	VOLATILIZATION	INHALATION/SKIN CONTACT	HUMAN ANIMALS
GRAIN/FOLIAGE	MANUFACTURING/FEEDING*	FOOD/INGESTION	HUMAN ANIMALS
CROP RESIDUE	OVERLAND FLOW*	SURFACE WATER (POTABLE WATER)/INGESTION	HUMAN FISH
RUNOFF	OVERLAND FLOW*	SURFACE WATER (POTABLE WATER AND FOOD CHAIN) INGESTION	HUMAN FISH
ERODED SOIL PARTICLES	OVERLAND FLOW	SURFACE WATER (FOOD Chain)/INGESTION, CONTACT	FISH
LEACHATE	LEACHING/PERCOLATION*	GROUNDWATER (POTABLE WATER)/INGESTION	HUMAN ANIMALS

*ENVIRONMENTAL FLUX OF CONCERN TO EITHER ON-SITE OR OFF-SITE RECEPTORS

TABLE 2 INFLUENCE OF CONSERVATION TILLAGE ON MASS BALANCE VARIABLES

Zone of Interest Plant Canopy and Surface Residue	Relative Change from Conventional Tillage	Flux of Concern to Off-Site Exposure	Pollution Concern
APPLY 1			
DEGRADATION	large increase		
VOLAT1	unknown	x	air
PLANT UPTAKE	large increase	x	foodstuff
HARVEST	no impact		
FOLIAR/RESIDUE WASHOFF	small increase	x	surface water
EROSP	large increase	x	surface water
VOLAT2	large increase	x	air
VOLAT3	large increase	x	air
SOIL SURFACE			
APPLY 2			
DEGRADATION	small increase		
VOLAT3	small reduction	x	air
EROSS	large reduction	x	surface water
RUNOFF	large reduction	x	surface water
LEACHING1	large increase	x	groundwater
VOLAT4	large reduction	x	air
FOLIAR/RESIDUE WASHOFF	large increase	x	surface water
ROOT ZONE			
APPLY 3			
DEGRADATION	no impact		
VOLAT4	large reduction	x	air
LEACHING2	large increase	x	groundwater
PLANT UPTAKE	no impact		foodstuff

Table 3 Impact of conservation tillage on soil properties, activities, and processes

- - - - Property/Activity - - - -		- - - - Processes - - - -	
Increase	Decrease	Increase	Decrease
Organic matter	soil temp.	infiltration	runoff
Microbial population	pH	hydraulic conductivity	water erosion evaporation
Soil aggregation	exchangeable calcium and magnesium	nitrogen immobilization	wind erosion
Bioturbation		leaching	
Soil structure	nitrate-nitrogen		
Exchangeable aluminum and manganese	bulk density*		
Water storage			
Bulk density*			
Porosity			
Available phosphorus and potassium			
Organic nitrogen			

*Function of soil type and climatic conditions.

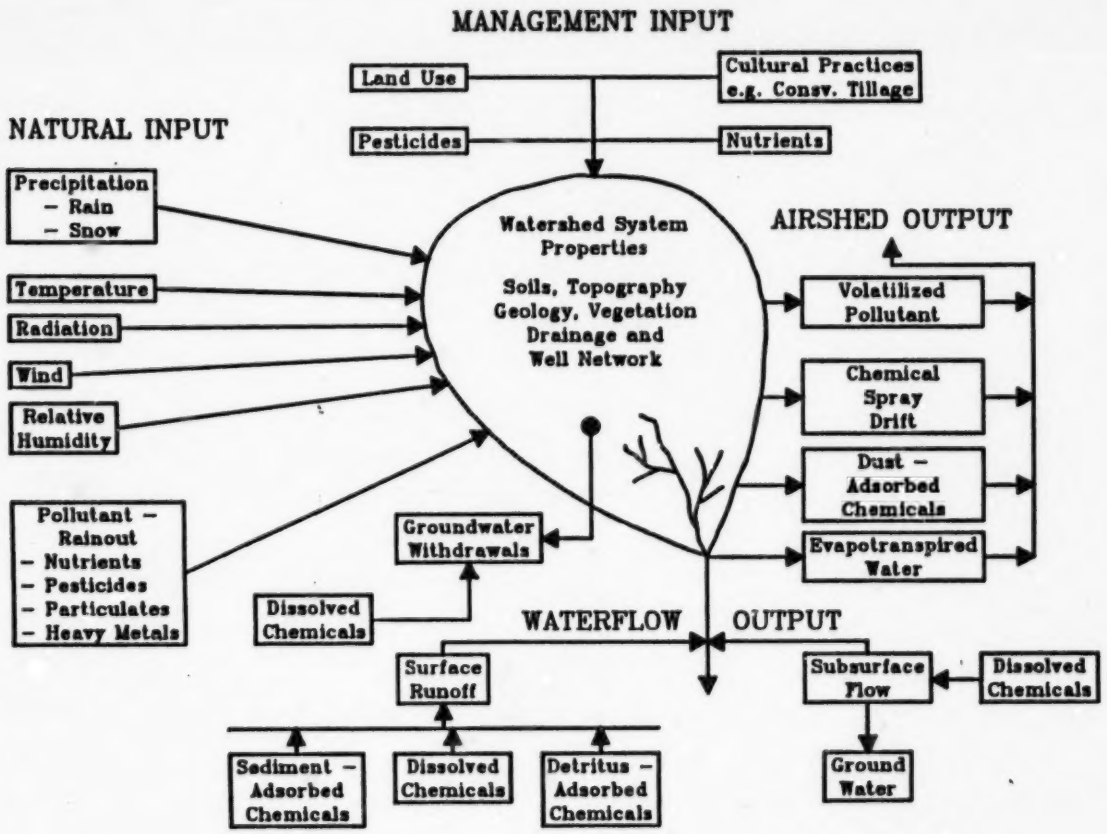

Figure 1

Factors Influencing the Behavior and Export of Agricultural Chemicals from an Agricultural Watershed. (After Bailey, and Swank, 1983)

(Reproduced from Agricultural Management and Water Quality, F.W. Schaller and G.W. Bailey, eds., p. 34, by permission of Iowa State University Press, Ames, Iowa.

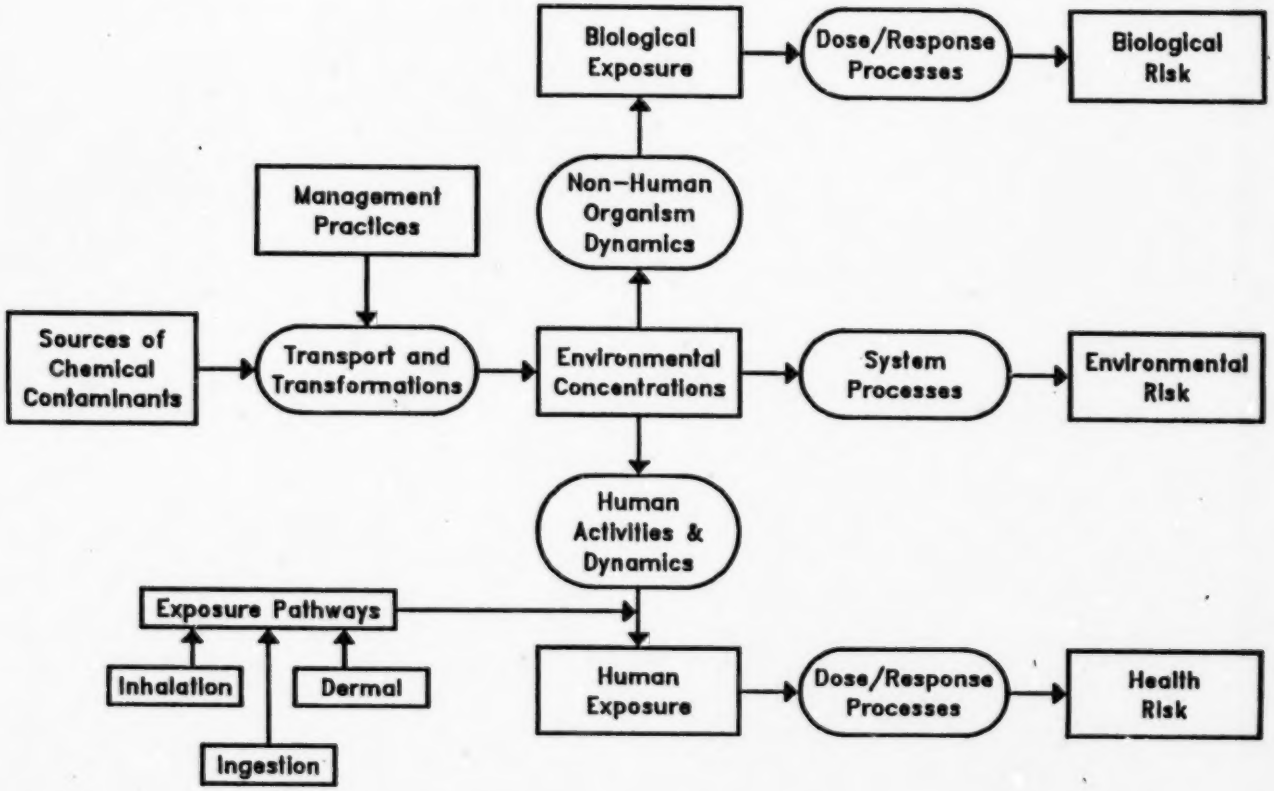

Figure 2. Concept of Exposure and Risk Assessment

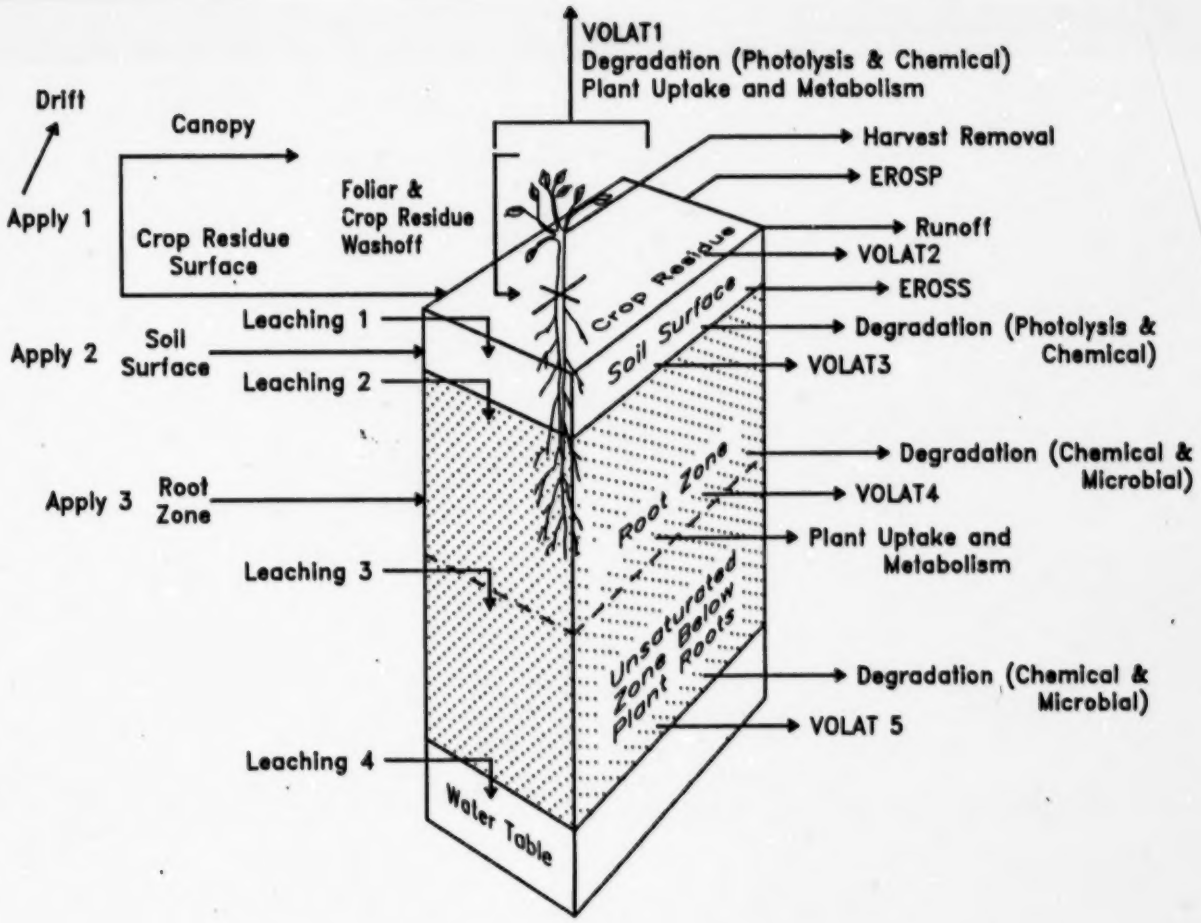

Figure 3. Pesticide–Soil–Plant Mass Balance.